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Aoyama et al.

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(54) **IMPLEMENTING SPIN TORQUE OSCILLATOR ERASURE PREVENTION IN MICROWAVE-ASSISTED MAGNETIC RECORDING (MAMR) HARD DISK DRIVES**

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G11B 5/31 (2006.01)
G11B 5/127 (2006.01)

(52) **U.S. Cl.**
CPC ***G11B 5/3133*** (2013.01); ***G11B 5/1278*** (2013.01)

(58) **Field of Classification Search**
CPC G11B 5/1278; G11B 5/3133
USPC 360/125.3, 324.2
See application file for complete search history.

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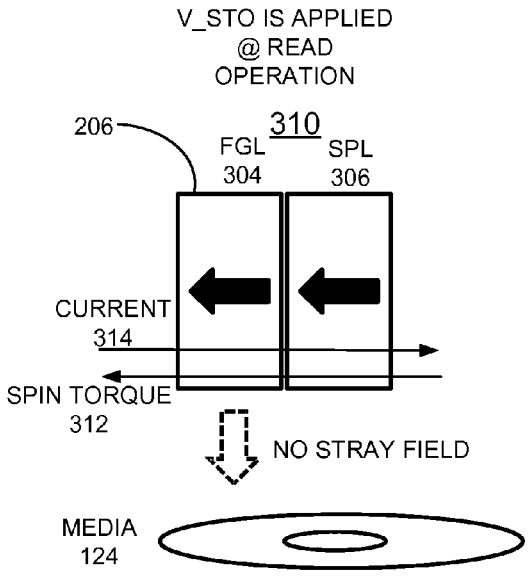
(57) **ABSTRACT**

A method, apparatus, and system are provided for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs). A first voltage is applied to an STO element in the MAMR head at the time of write operation. A second voltage is applied to the STO element at the time of read operation, or not write operation, to prevent STO erasure otherwise resulting from remnant magnetization of STO at the time of read operation.

11 Claims, 12 Drawing Sheets



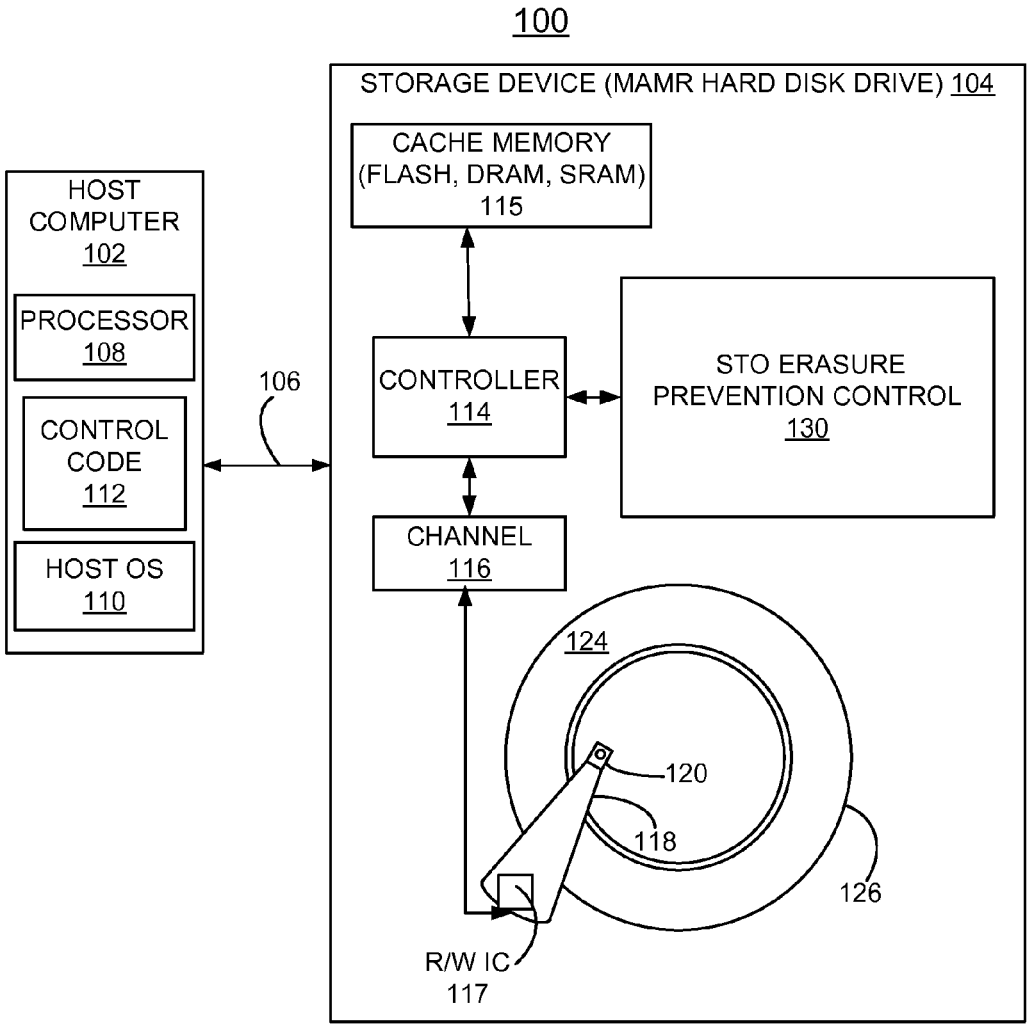

100
STORAGE DEVICE (MAMR HARD DISK DRIVE) 104
CACHE MEMORY (FLASH, DRAM, SRAM) 115
HOST COMPUTER 102
PROCESSOR 108
CONTROL CODE 112
HOST OS 110
106
CONTROLLER 114
STO ERASURE PREVENTION CONTROL 130
CHANNEL 116
124
120
118
126
R/W IC 117

FIG. 1

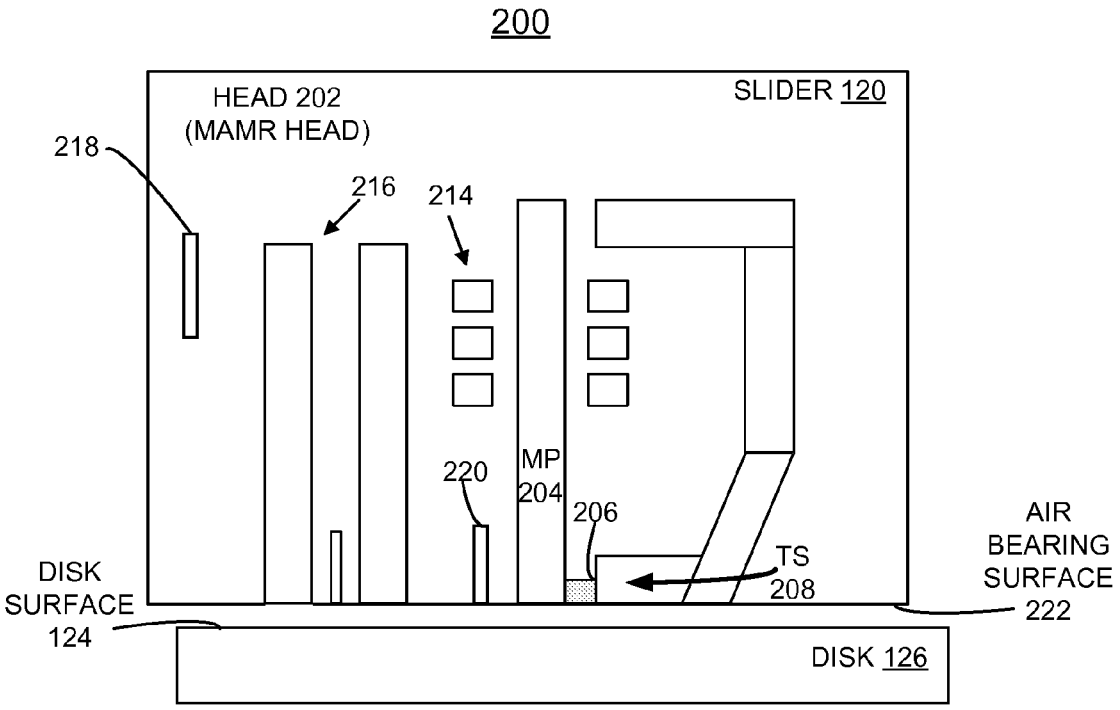

200
HEAD 202
(MAMR HEAD)
SLIDER 120
218
216
214
220
MP
204
206
TS
208
AIR
BEARING
SURFACE
222
DISK
SURFACE
124
DISK 126

FIG. 2A

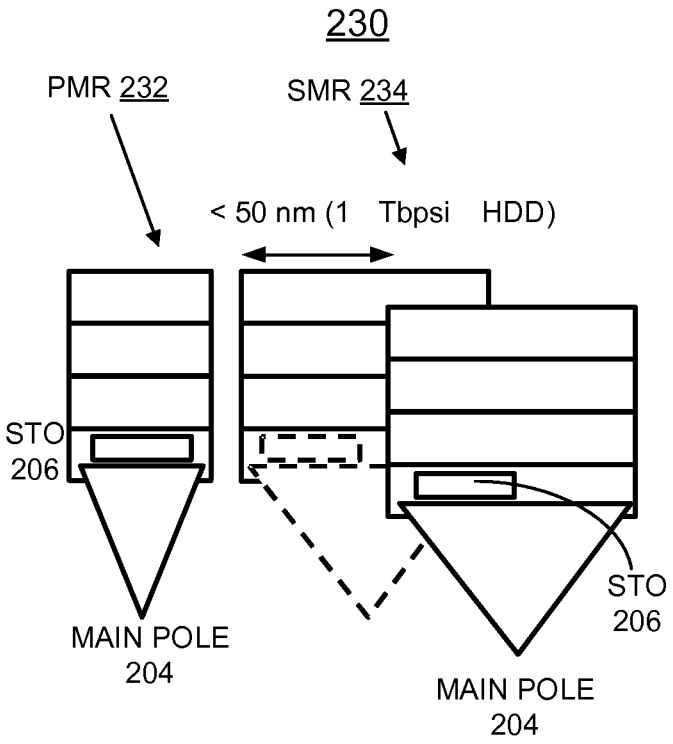

230
PMR 232
SMR 234
< 50 nm (1 Tbpsi HDD)
STO
206
MAIN POLE
204
STO
206
MAIN POLE
204

FIG. 2B

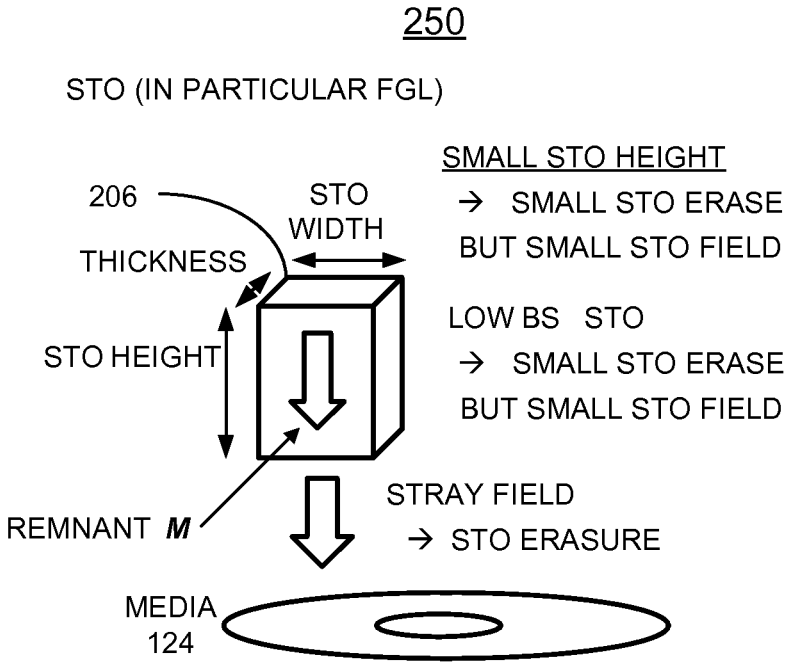

250
STO (IN PARTICULAR FGL)
206
STO WIDTH
THICKNESS
STO HEIGHT
REMNANT M
MEDIA 124
SMALL STO HEIGHT
→ SMALL STO ERASE
BUT SMALL STO FIELD
LOW BS STO
→ SMALL STO ERASE
BUT SMALL STO FIELD
STRAY FIELD
→ STO ERASURE

FIG. 2C

PRIOR ART

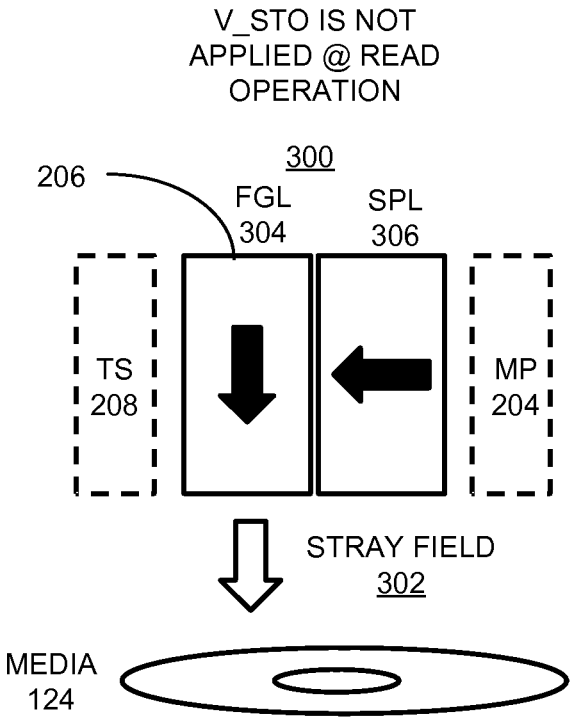


FIG. 3A

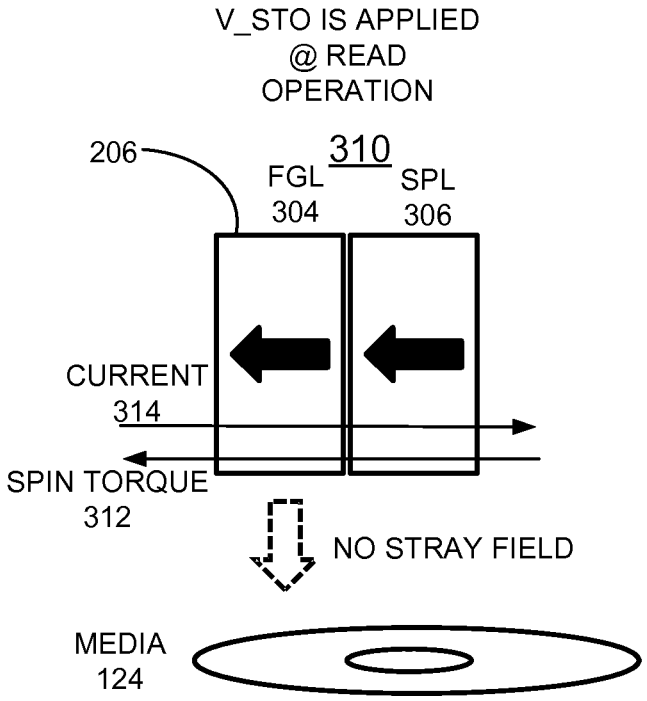

V_STO IS APPLIED
@ READ
OPERATION
206
310
FGL
304
SPL
306
CURRENT
314
SPIN TORQUE
312
NO STRAY FIELD
MEDIA
124

FIG. 3B

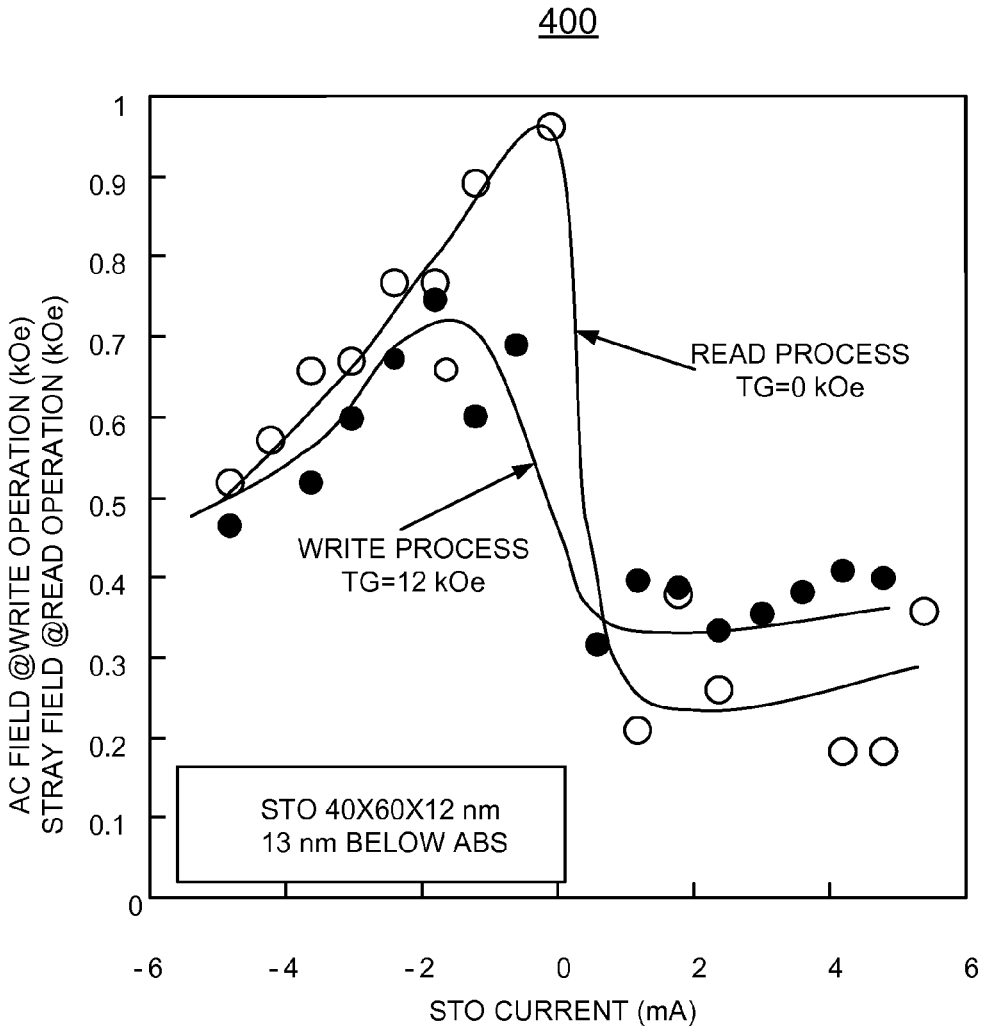

400
AC FIELD @WRITE OPERATION (kOe)
STRAY FIELD @READ OPERATION (kOe)
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
READ PROCESS
TG=0 kOe
WRITE PROCESS
TG=12 kOe
STO 40X60X12 nm
13 nm BELOW ABS
-6
-4
-2
0
2
4
6
STO CURRENT (mA)

FIG. 4

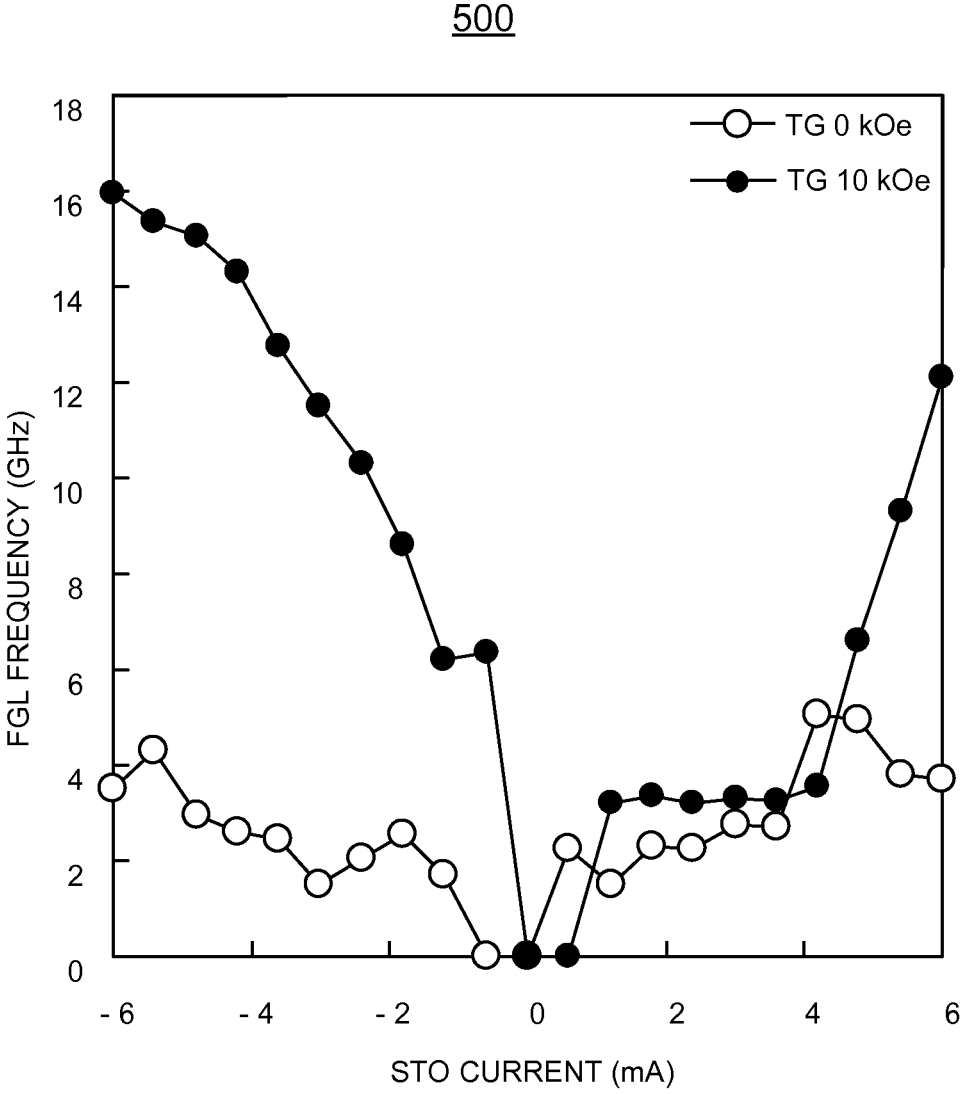

500
TG 0 kOe
TG 10 kOe
FGL FREQUENCY (GHz)
18
16
14
12
10
8
6
4
2
0
- 6
- 4
- 2
0
2
4
6
STO CURRENT (mA)

FIG. 5

600

	TG FIELD 602	STO CURRENT 604	STO FIELD 606	FGL FREQ 608
WRITE W/ STO BIAS	12 kOe	-3 mA	0.6 kOe	15 GHz
RE W/O STO BIAS	0 kOe	0 mA	1.0 kOe	~0 GHz
READ W/STO BIAS	0 kOe	-3 mA	0.6 kOe	~0 GHz
READ W/ STO BIAS	0 kOe	+1 mA	0.3 kOe	~0 GHz

FIG. 6

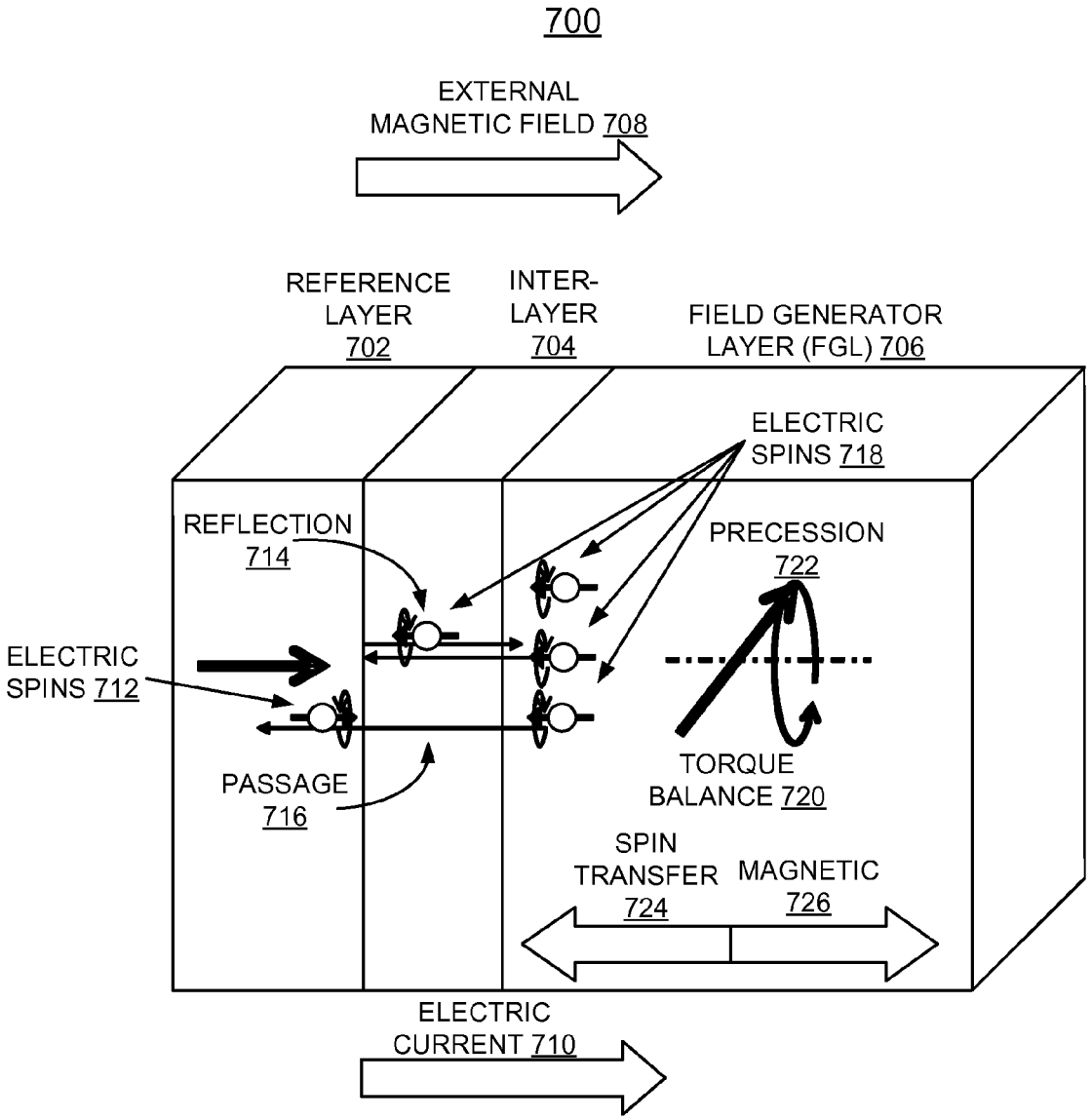

700
EXTERNAL
MAGNETIC FIELD 708
REFERENCE
LAYER
702
INTER-
LAYER
704
FIELD GENERATOR
LAYER (FGL) 706
ELECTRIC
SPINS 718
REFLECTION
714
PRECESSION
722
ELECTRIC
SPINS 712
PASSAGE
716
TORQUE
BALANCE 720
SPIN
TRANSFER
724
MAGNETIC
726
ELECTRIC
CURRENT 710

FIG. 7

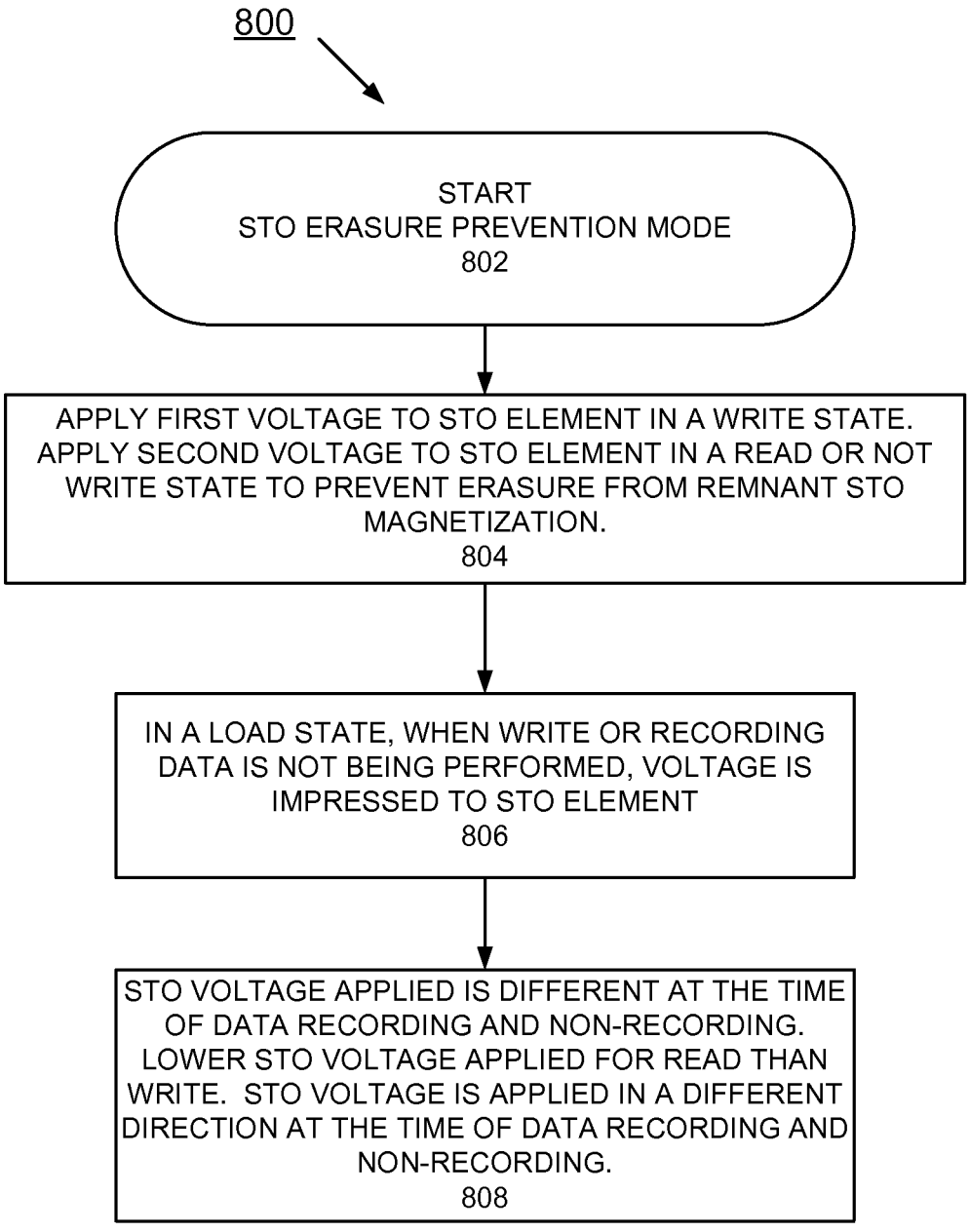
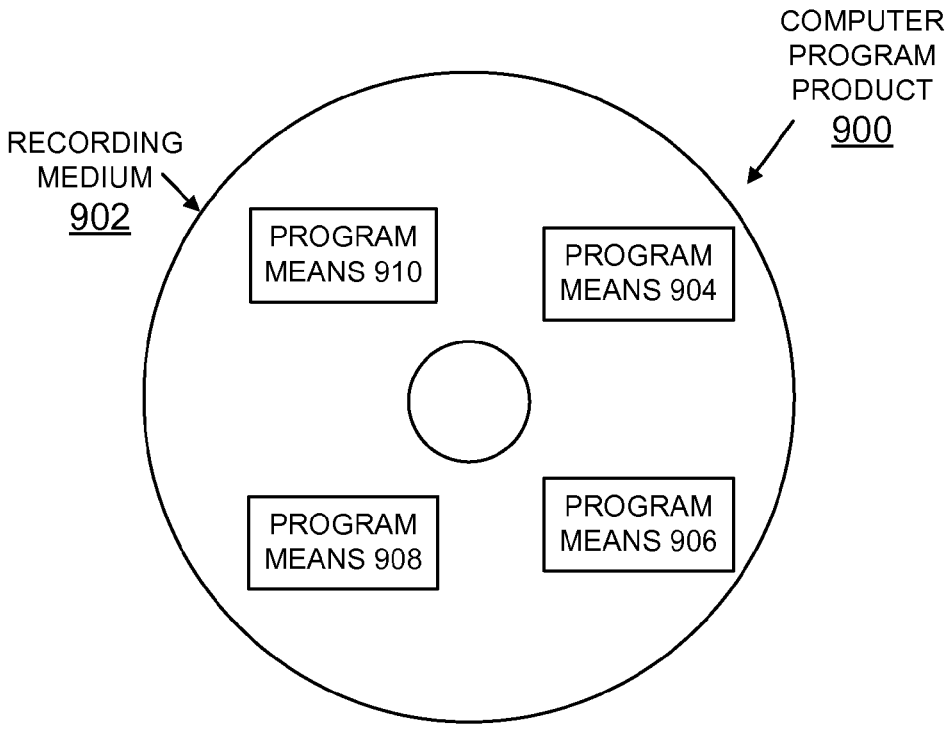

800
START
STO ERASURE PREVENTION MODE
802
APPLY FIRST VOLTAGE TO STO ELEMENT IN A WRITE STATE. APPLY SECOND VOLTAGE TO STO ELEMENT IN A READ OR NOT WRITE STATE TO PREVENT ERASURE FROM REMNANT STO MAGNETIZATION.
804
IN A LOAD STATE, WHEN WRITE OR RECORDING DATA IS NOT BEING PERFORMED, VOLTAGE IS IMPRESSED TO STO ELEMENT
806
STO VOLTAGE APPLIED IS DIFFERENT AT THE TIME OF DATA RECORDING AND NON-RECORDING. LOWER STO VOLTAGE APPLIED FOR READ THAN WRITE. STO VOLTAGE IS APPLIED IN A DIFFERENT DIRECTION AT THE TIME OF DATA RECORDING AND NON-RECORDING.
808

FIG. 8

FIG. 9


COMPUTER
PROGRAM
PRODUCT
900
RECORDING
MEDIUM
902
PROGRAM
MEANS 910
PROGRAM
MEANS 904
PROGRAM
MEANS 908
PROGRAM
MEANS 906

IMPLEMENTING SPIN TORQUE OSCILLATOR ERASURE PREVENTION IN MICROWAVE-ASSISTED MAGNETIC RECORDING (MAMR) HARD DISK DRIVES

FIELD OF THE INVENTION

The present invention relates generally to the data storage field, and more particularly, relates to a method, apparatus, and system for implementing spin-torque oscillator (STO) erasure prevention in microwave assisted magnetic recording (MAMR) hard disk drives (HDDs).

DESCRIPTION OF THE RELATED ART

Many data processing applications require long-term data storage and typically a high-degree of data integrity. Typically these needs are met by non-volatile data storage devices. Non-volatile storage or persistent media can be provided by a variety of devices, most commonly, by direct access storage devices (DASDs), which also are referred to as hard disk drives (HDDs).

Microwave Assisted Magnetic Recording (MAMR) uses a Spin Torque Oscillator (STO) to generate localized microwave radiation around the pole tip to improve the magnetic recording process. Using MAMR, magnetic media with high coercivity can be used to increase the bit density

A need exists for an effective mechanism for prevention of spin-torque oscillator (STO) erasure in microwave assisted magnetic recording (MAMR) hard disk drives (HDDs).

SUMMARY OF THE INVENTION

Aspects of the preferred embodiments are to provide a method, apparatus, and system for implementing spin-torque oscillator (STO) erasure prevention. Other important aspects of the preferred embodiments are to provide such method, apparatus, and system substantially without negative effect and to overcome some of the disadvantages of prior art arrangements.

In brief, a method, apparatus, and system are provided for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs). A first voltage is applied to an STO element in the MAMR head at the time of write operation. A second voltage is applied to the STO element at the time of read operation, or not write operation, to prevent STO erasure otherwise resulting from remnant magnetization of STO at the time of read operation.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention together with the above and other objects and advantages may best be understood from the following detailed description of the preferred embodiments of the invention illustrated in the drawings, wherein:

FIG. **1** is a block diagram representation illustrating a system for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs) in accordance with preferred embodiments;

FIG. **2**A illustrates example apparatus for spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs) in accordance with preferred embodiments;

FIGS. **2**B and **2**C illustrate example spin-torque oscillator (STO) aspect ratio and operation for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs);

FIGS. **3**A and **3**B respectively illustrate example operations of an STO with voltage not applied to the STO and voltage applied to the STO at the time of read operation in accordance with preferred embodiments;

FIGS. **4** and **5** respectively illustrate example waveforms of example AC field strength and higher field generation layer (FGL) with respect to STO current in accordance with preferred embodiments;

FIG. **6** is a chart illustrating example STO operation with respect to write and read operations with and without STO bias in accordance with preferred embodiments;

FIG. **7** schematically illustrates example STO operation with respect to write and read operation with and without STO bias in accordance with preferred embodiments;

FIG. **8** is a flow chart illustrating example operations for implementing spin-torque oscillator (STO) erasure prevention in MAMR HDDs in accordance with preferred embodiments; and

FIG. **9** is a block diagram illustrating a computer program product in accordance with preferred embodiments.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

In the following detailed description of embodiments of the invention, reference is made to the accompanying drawings, which illustrate example embodiments by which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the invention.

The terminology used herein is for the purpose of describing particular embodiments only and is not intended to be limiting of the invention. As used herein, the singular forms "a", "an" and "the" are intended to include the plural forms as well, unless the context clearly indicates otherwise. It will be further understood that the terms "comprises" and/or "comprising," when used in this specification, specify the presence of stated features, integers, steps, operations, elements, and/or components, but do not preclude the presence or addition of one or more other features, integers, steps, operations, elements, components, and/or groups thereof.

In accordance with features of the preferred embodiments, a method, apparatus, and system are provided for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs).

Having reference now to the drawings, in FIG. **1**, there is shown an example system generally designated by the reference character **100** for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs) in accordance with preferred embodiments. System **100** includes a host computer **102**, a storage device **104**, such as a hard disk drive (HDD) **104**, and an interface **106** between the host computer **102** and the storage device **104**.

As shown in FIG. **1**, host computer **102** includes a processor **108**, a host operating system **110**, and control code **112**. The storage device or microwave assisted magnetic recording (MAMR) hard disk drive **104** includes a controller **114** coupled to a cache memory **115**, for example, implemented with one or a combination of a flash memory, a dynamic random access memory (DRAM) and a static random access memory (SRAM), and coupled to a data channel **116**. The storage device or hard disk drive **104** includes a Read/Write

(R/W) integrated circuit (IC) **117** implementing spin-torque oscillator (STO) erasure prevention of the preferred embodiments. The storage device or hard disk drive **104** includes an arm **118** carrying a slider **120** for in accordance with preferred embodiments. The slider **120** flies over a writable disk surface **124** of a disk **126** and includes at least one STO for microwave assisted magnetic recording (MAMR), for example, integrated with the slider **120**.

In accordance with features of preferred embodiments, an STO erasure prevention control **130** for spin-torque oscillator (STO) erasure prevention is provided with the controller **114**.

System **100** including the host computer **102** and the MAMR HDD **104** is shown in simplified form sufficient for understanding the present embodiments. The illustrated host computer **102** together with the storage device or HDD **104** is not intended to imply architectural or functional limitations.

The preferred embodiments for spin-torque oscillator (STO) erasure prevention can be used with various hardware implementations and systems and various other internal hardware devices. While the control code **112** is shown in the host computer **102**, and the controller **114** is shown in the hard disk drive **104**, the control code **112** may reside in any suitable location, such as the hard disk drive **104** separate from host computer **102** and controller circuit **114** may reside in any suitable location, separate from hard disk drive **104**, for example, in the host computer **102**, and the like.

Referring now FIG. **2**A, there are shown example slider, head, and disk apparatus generally designated by the reference character **200** for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs) of the preferred embodiments. Apparatus **200** includes a recording head **202**, such as a MAMR head **202** provided with the slider **120**. The MAMR head **202** includes a main magnetic pole (MP) **204**, a spin-torque oscillator (STO) **206**, and a trailing shield **208** of the head writer. As shown, the MAMR head **202** includes a coil **214** positioned proximate the main magnetic pole MP **204**, a reader **216**, and a thermal flying height control **218**. The HAMR head **202** optionally includes an embedded contact sensor (ECS) **220** proximate the air bearing surface **222** of the MAMR head **202**.

Referring now to FIGS. **2**B and **2**C, there are shown example spin-torque oscillator (STO) operations and aspect ratio respectively generally designated by the reference characters **230**, **250** for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs).

Referring now FIG. **2**B, there are shown example spin-torque oscillator (STO) operations **230** with the STO **206** and main pole **204** illustrating Perpendicular Magnetic Recording (PMR) **232** and Shingled Magnetic Recording (SMR) **234**, where successively written data tracks partially overlap.

Referring now to FIG. **2**C, there are shown example spin-torque oscillator (STO) operations and example aspect ratio respectively **250** for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs). The example STO **206** is shown with an STO THICKNESS, an STO WIDTH and an STO HEIGHT. The example STO **206** illustrates that there is a high possibility that the erasure resulting from the remnant magnetization M of STO in the time of read operation with STO erasure that actualizes as the track density becomes high, for example, where the data track width and the STO WIDTH become narrow. The magnetic domain control depending on optimization of the aspect ratio of STO, selection of low Magnetic Flux Density (Bs) material, or multi-layer structure to make closed domain trades off microwave assisting effects.

FIGS. **3**A and **3**B respectively illustrate example operations respectively generally designated by the reference characters **300**, **310** of an STO with voltage not applied to the STO and voltage applied to the STO at the time of read operation in accordance with preferred embodiments. As shown, STO **206** includes a field generation layer (FGL) **304** and a spin polarization layer (SPL) **306** relative to a disk media **124**, and located between a main pole (MP) **204** and trailing shield (TS) **208** in FIG. **3**A. In FIG. **3**A, there is shown conventional operation **300** of an STO with voltage not applied to the STO at the time of read operation with a stray field **302** applied to the disk media **124**. In FIG. **3**B, there is shown STO operation **310** of the STO **206** with voltage applied to the STO at the time of read operation in accordance with preferred embodiments. STO operation **310** illustrates spin torque **312** and current **314** in opposite directions with minimized stray field or no stray field (removed by the V_STO used). The direction of the magnetization in FGL **304** is changed by the effect of spin torque and current **314** in opposite direction.

FIGS. **4** and **5** respectively illustrate example waveforms respectively generally designated by the reference characters **400**, **500** in accordance with preferred embodiments of example AC field strength and higher field generation layer (FGL) with respect to STO current shown relative to the horizontal axis. In FIG. **4**, waveforms **400** confirm reduction of stray field strength with STO current (positive). Reduction effect shows up with lower current density as compared to the current density in the write operation (about −3 mA). In FIG. **5**, waveforms **500** confirm higher frequency of STO field with STO current (negative) in the write operation. On the other hand, in the read operation when TG field is zero, precession frequency of the field generation layer (FGL) is quite small.

Referring to FIG. **6**, there is shown a chart illustrating example STO operation generally designated by the reference character **600** with respect to write and read operation with and without STO bias in accordance with preferred embodiments. For each of write with STO bias, read without STO bias, read with STO bias, and read with another STO bias, trailing gap (TG) field **602**, STO current **604**, STO field **606**, and FGL frequency **608** are shown. The trailing gap (TG) field **602** represents the field from the main pole **204** to the FGL layer of the STO. As shown, the TG field **602** and FLG frequency **608** are non-zero values with the write with STO bias. The read with STO bias providing a STO current in the opposite direction to the STO current for the write with STO bias provides the lowest STO field, for STO erasure prevention in accordance with features of the preferred embodiments.

Referring now to FIG. **7**, there is schematically illustrated example STO structure generally designated by the reference character **700** in accordance with preferred embodiments. STO **700** includes a reference layer **702**, an interlayer **704** and a field generation layer (FGL) **706**. As indicated by arrows, an external magnetic field **708** is generated responsive to an electric current **710** flowing from the reference layer **702** via the interlayer **704** to the field generation layer **706**. As shown, electric spins **712** are generated in the reference layer **702** with electric spin reflection **714** and passage **716** through interlayer **704** with electric spins **718** generated in the field generation layer (FGL) **706**. Due to spin transfer torque **720**, magnetization procession **722** is amplified in the field generation layer (FGL) **706** with spin transfer **724** and magnetic field **726**, as indicated by arrows in opposite directions.

Referring now to FIG. **8** there is shown a flow chart illustrating example operations generally designated by the reference character **800** for implementing spin-torque oscillator (STO) erasure prevention in MAMR HDDs in accordance

with preferred embodiments starting at a block **802**. As indicated in a block **804**, a first voltage is applied to an STO element in the MAMR head at the time of write operation, and a second voltage is applied to the STO element at the time of read operation, or not write operation, to prevent STO erasure otherwise resulting from remnant magnetization of STO at the time of read operation. As indicated in a block **806**, when write or recording data is not being performed, voltage is impressed to the STO element. As indicated in a block **808**, the STO voltage applied is different at the time of data recording (write) and non-recording (read). At block **808**, a lower STO voltage is applied at the time of non-recording (read) than data recording (write). At block **808**, the STO voltage is applied in a different direction at the time of data recording (write) and non-recording (read).

Referring now to FIG. **9**, an article of manufacture or a computer program product **900** of the preferred embodiments is illustrated. The computer program product **900** includes a computer readable recording medium **902**, such as, a floppy disk, a high capacity read only memory in the form of an optically read compact disk or CD-ROM, a tape, or another similar computer program product. Computer readable recording medium **902** stores program means or control code **904**, **906**, **908**, **910** on the medium **902** for carrying out the methods for implementing spin-torque oscillator (STO) erasure prevention for MAMR hard disk drives in accordance with preferred embodiments in the system **100** of FIG. **1**.

A sequence of program instructions or a logical assembly of one or more interrelated modules defined by the recorded program means or control code **904**, **906**, **908**, **910**, direct HDD controller **114** during MAMR HDD operation of preferred embodiments for carrying out the methods for implementing spin-torque oscillator (STO) erasure prevention for MAMR hard disk drives in accordance with preferred embodiments in the system **100** of FIG. **1**.

While the present invention has been described with reference to the details of the embodiments of the invention shown in the drawing, these details are not intended to limit the scope of the invention as claimed in the appended claims.

What is claimed is:

1. A method for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs) comprising:

providing a STO element; said STO element having a field generation layer (FGL) and a spin polarization layer (SPL) and located between a main pole (MP) and a trailing shield (TS);

applying a first voltage to a STO element at a time of write operation and generating first values of a trailing gap (TG) field between said main pole (MP) and said trailing shield (TS) and field generation layer (FGL) frequency of said STO element; and

applying a second voltage to a STO element at a time of read operation to prevent erasure resulting from remnant STO magnetization; said second voltage being lower than said first voltage and said second voltage having a different polarity than said first voltage, and generating second values of said trailing gap (TG) field between said main pole (MP) and said trailing shield (TS) and said field generation layer (FGL) frequency; said second values being near zero and substantially less than said first values.

2. The method as recited in claim **1**, wherein current through the STO element is lower with the second voltage applied to the STO element at the time of read operation than current through the STO element with the first voltage applied to the STO element at the time of write operation.

3. The method as recited in claim **1**, wherein the second voltage applied to the STO element at the time of read operation changes a direction of magnetization in said field generation layer (FGL) of the STO element.

4. An apparatus for implementing spin-torque oscillator (STO) erasure prevention for microwave assisted magnetic recording (MAMR) hard disk drives (HDDs), comprising:

a controller;

at least one disk; said disk including a disk media for storing data;

a spin-torque oscillator (STO) element for microwave assisted magnetic recording (MAMR); said STO element having a field generation layer (FGL) and a spin polarization layer (SPL) and located between a main pole (MP) and a trailing shield (TS);

said controller applying a first voltage to a STO element at a time of write operation and generating first values of a trailing gap (TG) field between said main pole (MP) and said trailing shield (TS) and field generation layer (FGL) frequency of said STO element; and

said controller applying a second voltage to a STO element at a time of read operation to prevent erasure resulting from remnant STO magnetization; said second voltage being lower than said first voltage and said second voltage having a different polarity than said first voltage, and generating second values of said trailing gap (TG) field between said main pole (MP) and said trailing shield (TS) and said field generation layer (FGL) frequency; said second values being near zero and substantially less than said first values.

5. The apparatus as recited in claim **4** includes control code stored on a non-transitory computer readable medium, and wherein said controller uses said control code to effectively prevent spin-torque oscillator (STO) erasure.

6. The apparatus as recited in claim **4**, wherein current through the STO element is lower with the second voltage applied to the STO element at the time of read operation than current through the STO element with the first voltage applied to the STO element at the time of write operation.

7. The apparatus as recited in claim **4**, wherein said controller applying a second voltage to the STO element at the time of read operation changes a direction of magnetization in said field generation layer (FGL) of the STO element.

8. The apparatus as recited in claim **4**, wherein said controller applying a second voltage to a STO element at a time of read operation to prevent erasure resulting from remnant STO magnetization includes said controller providing a current flow at the time of read operation in an opposite direction as a current flow at the time of write operation.

9. A system for implementing prevention of spin-torque oscillator (STO) erasure comprising:

a microwave assisted magnetic recording (MAMR) hard disk drive (HDD), said MAMR HDD comprising a controller;

at least one disk; said disk including a disk media for storing data;

a spin-torque oscillator (STO) element for microwave assisted magnetic recording (MAMR); said STO element having a field generation layer (FGL) and a spin polarization layer (SPL) and located between a main pole (MP) and a trailing shield (TS);

said controller applying a first voltage to a STO element at a time of write operation and generating first values of a trailing gap (TG) field between said main pole (MP) and said trailing shield (TS) and field generation layer (FGL) frequency of said STO element; and

said controller applying a second voltage to a STO element at a time of read operation to prevent erasure resulting from remnant STO magnetization; said second voltage being lower than said first voltage and said second voltage having a different polarity than said first voltage, and generating second values of said trailing gap (TG) field between said main pole (MP) and said trailing shield (TS) and said field generation layer (FGL) frequency; said second values being near zero and substantially less than said first values.

10. The system as recited in claim **9** includes control code stored on a non-transitory computer readable medium, and wherein said controller uses said control code to implement prevention of spin-torque oscillator (STO) erasure.

11. The system as recited in claim **9**, wherein said controller applying a second voltage to a STO element at a time of read operation to prevent erasure resulting from remnant STO magnetization includes said controller providing a current flow at the time of read operation in an opposite direction as a current flow at the time of write operation.

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